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rowth experiments with the rawn *Palaemon serratus* Pennant ed with fresh and compounded foods

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Abstract

A series of short-term feeding experiments, normally lasting 4 weeks, was made using individually-held juvenile *Palaemon serratus* Pennant, in order to investigate some of the problems involved in compounding diets for prawns and to evaluate potential dietary ingredients. Experimental diets were finely milled in a ball mill and bound into jellies, using either gelatin or agar dissolved in sea water. A standard test diet resembling rations which have been successfully developed for trout and catfish was formulated, of which the major component was white fish meal, 45 per cent. Different protein-rich food meals were tested in this diet in place of white fish meal, and Norwegian shrimp meal (dried shrimp waste) was found to give the best growth. The diet containing white fish meal was second best. The addition of extra lipids (corn oil or cod liver oil) or a comprehensive vitamin premix to these diets conferred no advantage.

Three experiments to determine the minimum protein level which is compatible with maximum or near maximum growth suggested that levels between 30-40 per cent should be satisfactory.

None of the compounded diets tested gave growth as good as fresh foods such as mussel (*Mytilus edulis*) mantle, shrimp (*Crangon vulgaris*) tail meat or crab (*Carcinus maenas*) gonad and digestive gland. In experiments lasting 4 weeks, growth on the best compounded diet was only 86.1 per cent of that on mussel mantle. The same diet gave 75.8 per cent of the growth on mussel mantle in a 12 week experiment with individually-held prawns and 79.9 per cent of the growth on halves of mussel in experiments with populations of *P. serratus* held in outdoor tanks for 13 weeks. Experiments in which mussel mantle which had been processed in different ways was fed to juvenile prawns pointed to the presence of a labile growth factor in this tissue and this was supported by experiments in which mussel mantle was fed as a once per week supplement to compounded diets. By supplementing compounded diets in this way it was possible to achieve growth equal to that on mussel mantle. Evidence was also found for a growth factor in crab gonad or digestive gland but not in the shrimp tail meat. The factor was not identified.

Two experiments with juveniles of the prawn *Pandalus platyceros* Brandt showed that their short-term growth on compounded diets was similar to that of *P. serratus* but over a longer period their performance declined.

Some of the problems associated with formulating diets for prawns are discussed.

ntroduction

lies on methods for the cultivation of prawns have been progress at Conway since 1964 (Reeve 1969; Forster 0). On the basis of the work completed to date it is eved that if prawn culture is to succeed commercially in United Kingdom it must be practised on an intensive is. A prerequisite of such a system is a suitable diet. oods compounded from basic food meals such as fish- l and soya bean meal are now routinely used in fish ure, e.g. for trout, carp, ayu, eels and yellow tail (Nomura Fuji 1969) and for catfish (Anon. 1970). However, ough prawn culture has been practised in certain parts he world for many years, compounded diets formulated cifically for prawns have not been used. In Japan, where wn farming has reached its most sophisticated level, a ture of trash fish, shrimps and clams is fed to prawns in ds (Hudinaga 1969). Freshly-prepared foods of this kind e many disadvantages: they tend to decompose rapidly, sing deoxygenation in certain parts of the ponds; they uire daily preparation and the ingredients must either be ained fresh each day or stored in freezers; also, the supply he ingredients may be vulnerable to prevailing weather ditions and the quality liable to seasonable variation. he successful development of compounded diets for wns would eliminate most of these problems. In a dry n, e.g. as pellets or as a dry meal mix, such diets can be ed at room temperature for several weeks. When ably bound their stability in water is good (Forster 1972) they are particularly adaptable to automatic feeding cedures. Finally, if the ingredients used are those com- ly employed in the formulation of other animal feeds, lar supplies at moderate prices are assured.

he objectives of the work reported in this paper were to some empirically formulated diets and the effect of some or dietary ingredients in growth experiments with wns and to compare the growth achieved with that ined on fresh foods such as mussels, shrimps and crabs rster 1970). The work was part of a general investigation problems of feed formulation for prawns (see also ster 1972 and Forster and Gabbott 1971), during which of the authors (JRMF) worked for some of the time at Marine Science Laboratories, Menai Bridge, North es.

xperimental lethods

OWTH EXPERIMENTS

s were tested in short-term feeding experiments usually ng for 4 weeks. The prawns used in these trials were *emon serratus* Pennant juveniles (100–300 mg initial live ht). These were reared at Conway using the methods ribed by Forster (1970), although occasionally juveniles ured from the wild were used. Juvenile prawns of this were used because they show large proportional weight ements in short periods and can be kept in relatively l containers. Growth was estimated by live-weighing, first drying the prawns on paper tissue, at the beginning end of each experiment. In a test on the accuracy of this nique five replicate weighings were made within 24 hours on 15 individual prawns (average weight 290 mg). The mean standard deviation was only 2.01.

In presenting the results the authors have tried to keep the tables as simple as possible to enable comparisons of dietary value to be made easily by inspection. Thus, when the results from several different experiments are compared, growth has been expressed in the text tables as a percentage of the growth observed on a control diet. The actual values recorded for growth, calculated as $\frac{W_t - W_o}{W_o} \times 100 =$ percentage live-weight increment, where W_o = initial weigh$_t$ and W_t = final weight, are given in more detail in an appendix (Appendix tables 1–5). The control food used in these trials was either a standard compounded diet or, in some experiments, fresh mussel (*Mytilus edulis*) tissue. When comparisons were made within only one experiment the actual values for growth are given in the text tables.

Most of the feeding experiments were made with prawns kept individually, since this avoids the problem of cannibalism (Reeve 1969; Forster 1970). Initially, one litre beakers were used as experimental vessels but this method requires aeration in each vessel, which results in excessive agitation of the food and disturbance to the prawn. Accordingly a system was devised in which individual prawns were kept in 2 litre polystyrene boxes (13 × 13 × 17 cm deep) which had several 1 mm holes drilled in the sides. Fifty-four of these vessels were placed in a shallow fibreglass tank filled with filtered sea water and maintained at 20 ± 2°C. They were deployed in a 6 × 9 randomized block design so that six foods could be tested with nine prawns subject to each treatment. By aerating vigorously at several points in the tank a good exchange of well-oxygenated water was obtained within the vessels, without direct agitation to either the prawns or the food. The water in the tank was changed twice weekly and the prawns were fed to excess every 24 hours; food remaining after this time was removed before fresh food was added.

Details of two experiments with prawn populations are given in the results section, with the account of the experiments.

DIET PREPARATION

Most of the dietary ingredients used were those commonly employed in other animal feed formulations. Experimental diets were blended and milled in a ball mill so that all the particles would pass through a 200μm mesh. However, many of the particles were much smaller, and usually between 50 and 70 per cent, by weight, would pass through a 90 μm mesh. This degree of milling reduced the possibility of selection of individual particles by the prawns. An experiment to study the effect of still finer milling showed that no advantage was conferred by such treatment.

In early experiments the food ingredients were bound into a water-stable jelly by stirring 5 g of the dry mix into 15 ml of a 6.7 per cent solution of gelatin in hot sea water and allowing the mix to set. These jellies were quite stable in sea water provided that the temperature did not exceed 22°C, but were not very satisfactory due to the large amounts of gelatin required, i.e. 1 g gelatin to 5 g dry diet. Since gelatin is a protein its inclusion in the diets must have influenced

their nutritional value. In certain comparative feeding trials the possible influence of gelatin was not critical but in other experiments, for example to determine the influence of different dietary protein levels, the use of gelatin was most undesirable; in these and later experiments jellies were made using agar (1 per cent solution in sea water). Agar jellies had the additional advantage that they were stable at higher water temperatures, >28°C (Forster 1972). Jellies were made once per week and stored at 5°C.

For initial experiments a diet, termed Diet A, was formulated based on compositions used in some trout and catfish diets; its composition is given in Table 1. This diet was acceptable to the prawns, giving satisfactory growth and survival in preliminary experiments, and was used in feeding trials as a control. However, in some feeding experiments described below it was found that if the white fish meal component of Diet A was replaced by Norwegian shrimp meal, an improvement in growth was obtained, and in some later experiments this improved formulation, termed Diet B (see Table 1), was used as a control in preference to Diet A.

In all experiments pieces of fresh mussel (*Mytilus edulis*) mantle were fed to one of the six groups of nine prawns so that, in addition to comparisons between different compounded diets, comparisons could also be made with a fresh food of established value. Mussel has been found to be a satisfactory food for prawns, some *P. serratus* having been reared through four generations on this diet alone (Wickins 1972*a*). One disadvantage of mussel as a standard food is that the condition, and probably therefore the food value, of the mantle varies seasonally in relation to the breeding cycle. In an attempt to reduce the possible effects of this variation on the prawns in feeding experiments, the only mussels used were those in which the mantle was in a good, 'full', condition but which were not so ripe that the reproductive products would ooze freely from cut sections.

TABLE 1 *Composition of Diet A. In some later experiments a modification of this formula (Diet B) was used which contained Norwegian shrimp meal (see note 3, Table 2) in place of white fish meal.*

Dietary components	%w/w
White fish meal (Hull and Grimsby)	45
Dried skim milk	10
Dried distiller's solubles	10
Wheat germ	10
Brewer's yeast	5
Whole shrimp meal[1]	5
Seaweed meal[2]	5
Soya bean meal (ex.)	2
Cotton seed meal (ex.)	2
Ground nut meal (ex.)	2
Maize gluten meal	2
Wheat meal	2

Notes: [1]Prepared at Conway by oven drying (100°C, 24 hours) whole shrimp, *Crangon vulgaris*.
[2]Prepared at Conway by oven drying (100°C, 24 hours) seaweed collected from the shore.

Results

EXPERIMENTS WITH DIFFERENT FOOD INGREDIENTS AND SUPPLEMENTS

Protein sources

There are a number of meals of high protein content in the formulation of animal feeds which could serv suitable sources of protein for prawn diets. These incl meals of animal origin, such as the various fish-meals, r meal, whale meat meal or shrimp 'waste' meal (see Tab notes 3 and 5); meals of plant origin, such as soya bean r (ex.); and certain microbially derived proteins (single proteins), e.g. B.P. protein concentrate (Lainé 1969; Sha lady 1969). In addition to the meals mentioned ab accelerated freeze-dried egg (AFD egg) and the pure prot casein and egg albumin were also tested. These pro sources have been tested extensively with other anim (Bender 1969) and were therefore of interest for comparis Two laboratory-prepared meals, freeze-dried fish-meal *P. serratus* meal (Table 2, notes 2 and 4), were also tes No attempt was made to adjust the protein levels in rations (Table 2); the test ingredients were simply sub tuted in place of the white fish meal in Diet A on a wei for weight basis. Gelatin was used as a binder in all th trials. The diets were fed to individually-held prawns i series of 6×9 factorial experiments lasting 4 weeks, a growth was compared inter-experimentally by reference t control (Diet A).

There is a danger in *ad libitum* feeding experiments of t kind that differences between the nutritional value of diets will be obscured by variations in the palatability of food to the animals. Observations of the prawns during experiments showed that they fed freely on all the diets a they were frequently seen to have food present in th stomachs (proventriculi), but it is not known whether total consumption of each diet was the same. It is possible to be certain therefore that differences in growth the test diets may not have been partly due to differences their acceptability.

The results (Table 2) show that growth on the diets c taining the 'crustacean' meals (Norwegian shrimp meal a *P. serratus* meal) was slightly better than on the white f meal control diet (Diet A) and that the diets containing other fish-meals (Peruvian fish-meal and Norwegian herr meal) gave slightly poorer growth than the control. Of other food meals the rations containing meat meal and B protein concentrate gave better growth than those contain whale meat meal and soya bean meal (ex.), but these were considerably poorer than the control. The diets contain AFD egg and the pure proteins casein and egg albumin a gave poorer growth than the control, although the t experiments with AFD egg gave widely diverging results a need to be repeated.

It was concluded that Norwegian shrimp meal or one the fish-meals was likely to be most suitable as a ma source of protein in rations for *P. serratus*. It should emphasized, however, that in none of these trials was growth on an experimental diet as good as the growth mussel mantle. The mean growth in 16 different experime on Diet A was only 55.9 per cent of the growth on mus mantle. The superiority of mussel mantle and other fr foods is discussed further below.

BLE 2 *Results from a series of experiments lasting 4 weeks to compare the growth (mean percentage increase in live weight) of* P. serratus *juveniles fed with diets containing different high protein meals substituted for white fish meal in Diet A (Table 1). The results are expressed as a percentage of the growth on Diet A. See also Appendix table 1*

h protein meal stituted for white meal in Diet A)	Origin	Approximate diet protein content %[1] (excl. gelatin)	Growth relative to growth on Diet A (= 100)			
			Series 1	± S.E.	Series 2	± S.E.
erratus meal[2]	Animal	37	117.6	7.6	–	–
wegian shrimp meal[3]	,,	37	116.6	7.5	107.4	15.5
uvian fish-meal	,,	46	96.0	9.1	86.1	10.3
eze-dried fish-meal[4]	,,	62	83.4	7.2	92.2	9.8
wegian herring meal	,,	47	73.8	9.1	89.5	10.9
. protein concentrate	Microbial	46	69.1	7.2	70.1	9.8
ein	Animal	62	66.1	9.5	–	–
at meal[5]	,,	38	66.6	9.1	63.7	10.3
g albumin	,,	62	61.7	10.0	–	–
a bean meal (ex.)	Vegetable	38	51.0	7.2	–	–
elerated freeze-dried egg	Animal	41	24.8	15.5	75.3	9.5
ale meat meal	,,	49	46.4	9.6	46.7	10.9

tes: [1]Calculated using values for protein content provided by the suppliers of the different meals and from estimated values for meals which were prepared in the laboratory.
[2]As 3 but prepared in the laboratory from *P. serratus* waste (see note 3).
[3]Dried shrimp waste ('heads' and tails after peeling) mainly from *Pandalus borealis;* produced in Norway.
[4]Milled freeze-dried cod fillets.
[5]Dried slaughterhouse offal.

ldition of extra lipids

An experiment was made to determine the influence of ding extra lipids to Diet B. Cod liver oil and corn oil were lded to the diet at levels of 7.5 and 15.0 per cent w/w. The ets were bound with gelatin and fed to groups of nine dividually-held prawns for 4 weeks. The results are given Table 3. The addition of extra lipid to Diet B conferred no lvantage; at 7.5 per cent supplementation there was little fluence on growth, but at 15.0 per cent growth was sigficantly reduced ($P < 0.001$).

ABLE 3 *Results from a 4-week experiment to determine the influence of supplemental lipids in Diet B on growth (mean percentage increase in live weight) of* P. serratus *juveniles, initial mean live weight 161.9 mg*

pid supplement % w/w		Mean live-weight increment % ± S.E.	
d liver oil	7.5	82.6	8.2
	15.0	39.7	8.2
rn oil	7.5	69.9	8.2
	15.0	40.8	8.2
et B — no supplement		79.4	8.2

ldition of supplementary vitamins

In the initial formulation of Diets A and B no defined amin supplements were added, since it was considered at vitamins occurring naturally in the ingredients, pecially in wheat germ, dried distiller's solubles and ewer's yeast, would provide reasonable vitamin levels hough the precise quantities and balance would most obably be far from ideal.

In order to check that a deficiency of vitamins was not sponsible for the differences in growth on fresh and comunded diets, a comprehensive vitamin supplement was ded to Diets A and B. The supplement was based on a rmulation specified by the Oregon Fish Commission for the Oregon moist pellet salmonid diet (Hublou *et al.* 1959) and Oregon pellet and starter mash specifications (Anon. 1968) but also included Vitamin A, Vitamin D_3, and choline chloride (Table 4). Four experiments were made in which the growth (mean percentage increase in live weight) of batches of nine individually-held prawns was compared on supplemented and unsupplemented Diets A and B. The results, expressed as a percentage of the mean growth increment on the unsupplemented diet, are given in Table 5.

TABLE 4 *Vitamin supplement used in prawn diets. The base material was oatmeal*

Vitamin	Quantity of vitamin per kg of supplement
Vitamin A	440 920 iu
Ascorbic acid	35.3 g
Biotin	23.6 mg
Vitamin B_{12}	2.4 mg
Choline chloride	266.8 g
Vitamin D_3	88 184 iu
Vitamin E	19 694 iu
Folic acid	280.0 mg
Inositol	36.8 g
Menadione	235.9 mg
Niacin	7.3 g
d-pantothenic acid	6.2 g
Pyridoxine	690.0 mg
Riboflavin	2.1 g
Thiamine	295.9 mg

The results show no improvement in the value of supplemented Diet A and a slight but insignificant (5 per cent level) improvement in the value of supplemented Diet B. Further experiments are required to establish whether or not this small improvement would be maintained. It was not sufficient to raise the food value to that of fresh foods; growth on the supplemented diets in experiments TR20 and TR31 was 71.6 and 90.6 per cent respectively of the growth on the mussel mantle control. On the basis of these results it seems very doubtful that a vitamin deficiency could be

TABLE 5 *Results from four experiments to determine the influence of supplemental vitamins in Diets A and B (Table 1) on the growth (mean percentage increase in live weight) of* P. serratus *juveniles. The result are expressed as a percentage of the growth on the unsupplemented diet. See also Appendix table 2*

Experiment number and duration	Compounded diet used	Growth relative to growth on unsupplemented diet (= 100)				Growth on mus mantle relative to growth on unsupplemented diet (= 100) ±
		Supplement level, 1.5%	± S.E.	Supplement level, 2.5%	± S.E.	
TR14, 4 weeks	A, gelatin-bound	–	–	82.4	15.5	143.5 1
TR29, 4 weeks	A, agar-bound	100.5	7.3	96.7	7.3	169.9
TR20*, 12 weeks	B (27.2% protein), agar-bound	118.2	10.3	–	–	164.8 1
TR31, 8 weeks	B, agar-bound	109.9	10.3	–	–	121.0

*This experiment is described more fully below (Diet 5) and shown in Figure 2.

responsible for the differences in growth between fresh and compounded diets in short-term feeding experiments. This conclusion was supported by the results of a 95 day experiment with two populations of juvenile *P. serratus* (see below and Table 12), in which the mean growth on vitamin-supplemented (1.5 per cent w/w) Diet B bound with agar was only 79.9 per cent of that on mussel-fed controls.

Dietary protein level

Three experiments were made to estimate the minimum protein level which was compatible with maximum or near-maximum growth, but since the food formulations used in this work gave growth which was substantially below maximum—as judged from comparisons with growth on mussel mantle—estimates of optimum protein levels must necessarily be tentative. However, it was hoped that these experiments would at least provide an indication of the range in which the protein level is likely to be optimal.

In two experiments the protein level of Diet B was either lowered—by adding 30, 50 and 70 per cent w/w of a 95:5 wheat starch/corn oil mixture—or increased (one experiment only) by adding 50 per cent w/w casein. The modifications resulted in diets which contained 69.4, 38.9, 27.2, 19.4 and 11.7 per cent protein. The addition of casein to increase the protein level was not very satisfactory in view of the poor results given by casein in the feeding experiments described above (Table 2), and a better estimate of the influence of higher protein levels was obtained in a third experiment using completely different diet formulations (Table 6).

The results are shown in Figure 1, in which the mean percentage increase in live weight in 4 weeks of groups of nine individually-held prawns is plotted against dietary protein content. The low growth on the casein-supplemented diet has been disregarded in drawing the curves. The results show that growth is markedly influenced by dietary protein level up to about 30 per cent protein, but above this level growth is influenced to a lesser extent. It is suggested that optimum protein levels in diets for *P. serratus* are likely to lie between 30 and 40 per cent. This will almost certainly vary with different sources of protein, but these results are in general agreement with optimum protein levels found for some fish diets; for example, Phillips and Brockway (1956) suggest that a dietary protein level of 28 per cent is desirable for trout, and Dupree and Sneed (1966) found good growth in channel catfish on diets with protein levels of between 28 and 40 per cent.

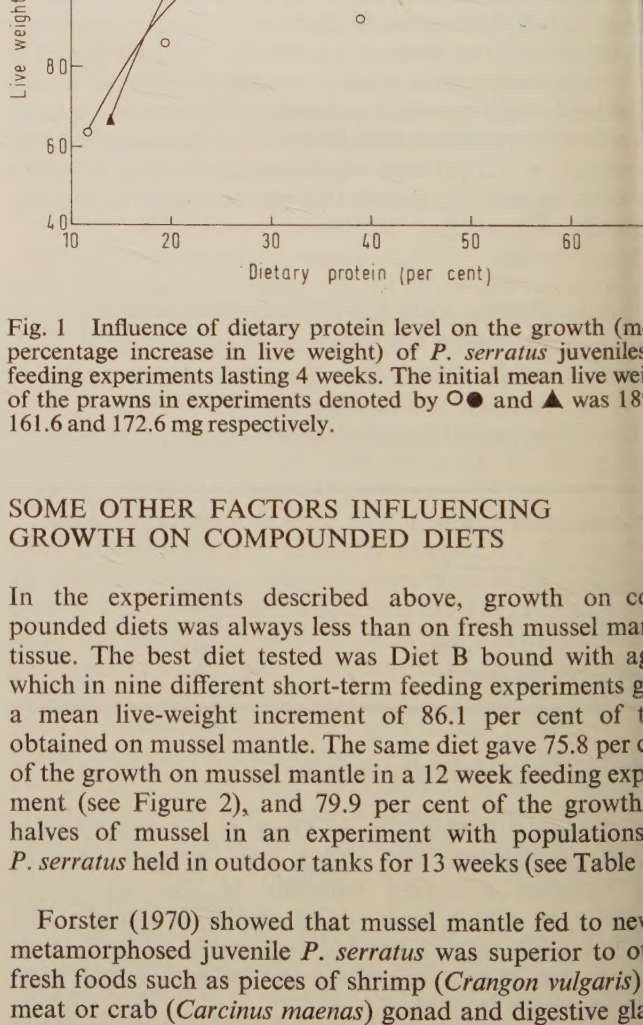


Fig. 1 Influence of dietary protein level on the growth (m percentage increase in live weight) of *P. serratus* juveniles feeding experiments lasting 4 weeks. The initial mean live we of the prawns in experiments denoted by ○● and ▲ was 18 161.6 and 172.6 mg respectively.

SOME OTHER FACTORS INFLUENCING GROWTH ON COMPOUNDED DIETS

In the experiments described above, growth on c pounded diets was always less than on fresh mussel ma tissue. The best diet tested was Diet B bound with a which in nine different short-term feeding experiments g a mean live-weight increment of 86.1 per cent of obtained on mussel mantle. The same diet gave 75.8 per of the growth on mussel mantle in a 12 week feeding exp ment (see Figure 2), and 79.9 per cent of the growth halves of mussel in an experiment with populations *P. serratus* held in outdoor tanks for 13 weeks (see Table

Forster (1970) showed that mussel mantle fed to ne metamorphosed juvenile *P. serratus* was superior to o fresh foods such as pieces of shrimp (*Crangon vulgaris*) meat or crab (*Carcinus maenas*) gonad and digestive gl In the present study the value of these foods to later juve (> 150 mg live weight) was determined. The results from 4-week experiments, given in Table 7, show that in cont to the previous work both shrimp tail meat and crab go and digestive gland gave slightly better growth than mu

BLE 6 *Composition of diets formulated to estimate the influence of dietary protein level on the growth of juvenile* P. serratus

Diet components, %, by weight						Protein content (%)
Protein mix[1]	Cellulose	Wheat starch	Mineral suppl.[2]	Corn oil	Vitamin suppl.[3]	
79.0	5	7.5	4	3	1.5	69.8
52.7	5	33.8	4	3	1.5	46.6
36.9	5	49.6	4	3	1.5	32.6
26.3	5	60.2	4	3	1.5	23.3
15.8	5	70.7	4	3	1.5	14.0

es: [1]Mixture containing 7 parts freeze-dried cod fish-meal and 1 part Norwegian shrimp meal.
[2]As used by Cowey, Adron, Blair and Pope (1970).
[3]See Table 4.

ntle. It is suggested therefore that the growth response of *serratus* to different fresh foods may change sometime ween the newly-metamorphosed and later juvenile stages. ese results also show that mussel mantle is not an asually good fresh food and therefore expose further the itations of the compounded diets which have been tested. nsidered below are some possible reasons for the eriority of fresh foods and the results of experiments ich were made to examine some of these possibilities.

BLE 7 *Results from two 4 week experiments to compare the growth (mean percentage increase in live weight) of juvenile* P. serratus *fed with different fresh foods. Initial mean live weight of prawns, 180.4 mg experiment 1 and 158.4 mg experiment 2*

et	Mean live-weight increment (%)			
	Exp. 1	± S.E.	Exp. 2	± S.E.
ssel mantle	197.0	14.2	202.2	13.0
ab gonad and digestive gland	235.1	13.4	251.5	14.1
rimp tail meat	204.6	13.4	237.3	13.0

latability

Juvenile *P. serratus* are voracious feeders and during the eding experiments responded vigorously to nearly all the mpounded diets which were tested. Each day when the od was changed food was seen to be present in the oventriculi of most of the prawns, and there were no vious discrepancies between those receiving fresh food id those on compounded diets. It is therefore considered likely that estimates of the food value of fresh and com-unded diets reflect differences in palatability.

igestibility

Studies on the efficiency of assimilation (percentage utrients absorbed) by *P. serratus* from compounded diets Forster and Gabbott 1971) have shown that protein and rbohydrates are digested very well. For example, from ree diets containing 60 per cent of different fish-meals, the ssimilation of protein averaged 89 per cent, and from a diet ntaining 60 per cent Norwegian shrimp meal 87.9 per cent f the protein was assimilated. From five diets containing 7.5 per cent wheat starch, cooked and uncooked potato arch, dextrin or glycogen, the mean assimilation of carbohydrate was 93.8 per cent. Hence it is considered unlikely that the relatively poor growth achieved on compounded diets was due to inefficient assimilation.

Leaching of dietary nutrients

The immersion of diets in sea water for 24 hours will result in the leaching out of some water-soluble nutrients. The extent of this leaching depends on the diet binder, but even with good binders such as agar some losses will occur (Forster 1972). Accordingly, an experiment was made to determine if such losses affected the food value of compounded diets. Diet A bound both into a jelly with gelatin and into a paste with guar gum 'UF' 5 per cent w/w (Forster 1972) was fed at 8-hour intervals for 4 weeks to groups of nine individually-held juvenile *P. serratus*. Their growth was compared with that of controls fed every 24 hours. Two groups of prawns were also fed with mussel mantle at the same intervals. The results, expressed as the mean percentage increase in live weight on each treatment, are given in Table 8. Although losses could occur within the 8 hour interval it was considered that if nutrient leaching was critical to the food value of compounded diets, growth of the 8 hour-fed prawns should be better than that of the 24 hour-fed animals. The results show that the converse was the case and that on the compounded diets the 24 hour-fed prawns grew significantly better ($P < 0.02$) than those fed every 8 hours. No explanation for these results is apparent, but it was concluded that in the experiments reported in this work losses of nutrients due to leaching were unlikely to be the cause of the poor growth on compounded diets.

TABLE 8 *Results of an experiment to compare the growth (mean percentage increase in live weight), on three diets, of* P. serratus *juveniles fed at 8 and 24 hour intervals. Initial mean live weight of prawns,103.9 mg*

Diet	Mean live-weight increment (%)			
	Food provided every 8 hours ± S.E.		Food provided every 24 hours ± S.E.	
Mussel mantle	272.7	14.3	254.9	14.3
Diet A bound with gelatin	105.6	14.3	123.8	14.3
Diet B bound with guar gum	106.8	14.3	123.3	14.3

Jellies made using fresh water or sea water

It was shown in three experiments in which Diet A, bound with gelatin dissolved either in fresh water or sea water, was fed for 4 weeks to groups of nine juvenile *P. serratus* that growth was significantly better ($P < 0.05$) when sea water was used. The results, expressed as a percentage of the live-weight increment on Diet A bound with gelatin in fresh water, were as follows:

Experiment	Growth on Diet A bound with gelatin in sea water relative to growth on Diet A bound with gelatin in fresh water (= 100) ± S.E.	
1	112.1	7.2
2	112.2	9.7
3	118.7	8.2

As a result of these experiments jellied diets in this work were all made using sea water as the solvent; this was also applied when agar was used, although no comparative tests were made between fresh water and sea water agar jellies. The reason for this improvement is not known.

Food storage

An experiment was made to find if the food value of jellied diets was affected by the period of storage during the experiments (i.e. 1 week at 5°C). Three groups of nine individually-held prawns (initial mean live weight 126.3 mg) were fed for 3 weeks with Diet A prepared with gelatin at different intervals. The results were as follows:

Diet treatment	Mean live-weight increment % ± S.E.	
Jelly prepared three times per week	90.6	9.7
Jelly prepared once per week	95.3	10.3
Jelly prepared once only at beginning of experiment	87.1	9.7

During the experiment the jelly which was kept for 3 weeks showed the development of darkened areas in the matrix and some mould on the surface. Although this apparently had little influence on nutritional value the preparation of jellies on a once per week basis was adopted as a standard procedure; there was no advantage in more frequent preparation.

Milling of ingredients

An experiment was made to find if there was any advantage in milling the food ingredients more finely. Two batches of nine individually-held juvenile *P. serratus* were fed for 4 weeks with Diet A (gelatin-bound) which had been milled for the usual time of 10 minutes and on the same diet which had been milled for 2 hours. After this extra milling, microscopic examination of the food particles showed that most of them were < 15 μm diameter and that the largest were only 40 μm diameter. Growth (mean percentage increase in live weight) on the two diets was 158.9 and 130.6 per cent respectively for the 10 minute-milled and 2 hour-milled diets and was not significantly different ($P > 0.05$). Thus no advantage was conferred by extra milling.

Response of larger prawns

The food requirements and growth responses of *P. serr* to compounded diets may change with age or size; indication that such changes may occur was noted abov is possible that the growth response to compounded die the small juveniles (100–300 mg live weight) used in work may not be characteristic of older animals. Acc ingly an experiment was made in which batches of individually-held larger juveniles (690 mg initial mean weight) were fed with Diets A and B (gelatin-bound) fresh mussel mantle. After 6 weeks the growth increme expressed as a percentage of the growth on mussel ma were 69.7 and 74.9 per cent on Diets A and B respectiv The response of these larger juveniles was therefore sim to that of animals in the 100–300 mg size range.

Response by Pandalus platyceros *Brandt*

In addition to *P. serratus* two other prawn species h been reared at Conway (Wickins 1972*b*). One of the *Pandalus platyceros* Brandt, was used in two experime during the present study so that its growth on compoun diets could be compared with the results obtained w *P. serratus*. In the first experiment two groups of individually-held *P. platyceros* (initial mean live weight 13 mg) were fed with either mussel mantle or Diet A bou with gelatin. After 6 weeks the mean percentage live-weig increments were 318.4 and 162.8 per cent respectively. T growth on Diet A expressed as a percentage of the growth mussel mantle was 51.1 per cent, which corresponds clos with the mean of 55.9 per cent found when *P. serratus* w fed the same diet. In a second experiment, which is describ in more detail below, growth among a population of juven *P. platyceros* fed for 13 weeks with Diet B bound with ag was only 47.3 per cent of that recorded from a populati fed with halves of mussel. The results therefore support t conclusion that the food value of even the best compound diet tested was poorer than that of fresh foods such mussel, and discount the possibility that the response *P. serratus* may have been atypical.

EXPERIMENTS WITH PROCESSED FRESH FOO

In the preceding paragraphs consideration has been giv to factors which may have been responsible for t superiority of fresh foods over compounded diets. T following section considers the basic nutritional value of t fresh food proteins and the effects of processing or bindi the diets in jelly or paste form. These aspects were studi by processing mussel mantle tissue in different ways bef feeding it to prawns.

Value of rebound processed mussel mantle

The first series of experiments involved testing mus mantle tissue which was processed in different ways a which was then rebound in various ways before feeding the prawns (Table 9). For experiments B1 and B2 new metamorphosed juveniles were used and growth increme were estimated in terms of total length. For experime TR2, TR3, TR6, TR12 and TR21 juvenile prawns in range 100–300 mg live weight were used and these w weighed live in the usual way.

The results show that the food value of mussel mantle

LE 9 *Summary of experiments made to test the food value to juvenile* P. serratus *of mussel mantle which was processed and bound in different ways. The results are expressed as a percentage of the growth (mean percentage increase in live weight) on fresh mussel mantle. See also Appendix table 3*

Experiment number and duration	Mussel mantle preparation	Binder and concentration used	Growth relative to growth on fresh mussel mantle (= 100) ± S.E.	
B1*, 3 weeks	Homogenized	Gelatin 6% w/v	45.9	3.0
	,,	Sodium alginate 6% w/v	25.3	3.1
B2*, 3 weeks	,,	Gelatin 6% w/v	59.2	3.0
	,,	Gelatin 10% w/v	49.7	3.2
	,,	Gelatin 20% w/v	45.5	3.0
TR2, 3 weeks	Oven-dried 80°C, 24 hours milled	Gelatin 20% w/w	76.8	8.8
TR3, 4 weeks	,,	Gelatin 20% w/w	51.3	5.6
TR6, 4 weeks	Homogenized	Gelatin 7.6% w/v	59.6	7.2
	Oven-dried 80°C, 24 hours, milled	Gelatin 20% w/w	58.1	8.0
	Freeze-dried, milled	Gelatin 20% w/w	50.0	7.2
TR12, 4 weeks	,,	Guar gum 5% w/w	48.1	6.4
TR21, 4 weeks	,,	Agar 3% w/w	59.0	5.9

ese experiments were made using newly-metamorphosed juvenile *P. serratus* and the growth increments were estimated in terms of total length.

stantially reduced by all the treatments. This could either ve been due to a direct effect of the processing or binding cedure on the nutritional value of mussel mantle, such as destruction of important nutrients, or to an indirect uence due to the addition of binders and the resulting nge in texture. If destruction of nutrients was responsible ould have occurred during oven drying, but it is unlikely t critical changes in the major nutrients would have urred during homogenization or freeze drying. Some truction could also have occurred due to binding with atin and agar, when the mussel mantle was briefly heated approximately 70°C; however, no heat was applied to the eze-dried material bound with guar gum (experiment 12, Table 9) and yet growth on this preparation was as lly affected as by the other treatments. It is possible that nges in the texture due to binding the mussel mantle parations may influence growth by reducing palatability, this is considered unlikely from observations of the ding responses of the prawns to these diets. Alternatively, presence of binders may influence the food value more ectly, for example by delaying the passage of food through alimentary canal and thus reducing the total food intake.

lue of processed mussel mantle which was not rebound

The possible significance of food texture and the presence binders was further investigated by determining the food ue of mussel mantle tissue which had been processed in ferent ways but which was not rebound (Table 10). All treatments caused slight changes in the texture of the ntle tissue which could have influenced palatability; for mple, boiled mantle became more friable, whereas deep-zen mantle became soft and rather watery when thawed. wever, observations of the prawns during the experi-nts showed that they responded actively and fed freely on mantle tissue irrespective of the different treatments, and s considered that palatability was not seriously affected.

The results show that the food value of the treated mantle was considerably reduced by the different treatments but that in general growth on the unbound treated mantle was better than on the bound preparations, the deep-frozen tissue excepted. The results point to two factors which may be acting together to cause the poor growth on the processed mantle preparations: (1) a direct effect caused by binding the preparations, (2) the destruction or denaturation of a labile nutrient or growth factor in the processed tissue which when present in fresh untreated mussel mantle promotes faster growth.

Evidence for a growth factor in some fresh foods

Some experiments were undertaken to investigate further the possible presence of a growth factor in mussel mantle and to find out if this factor was characteristic of other fresh foods, i.e. shrimp tail meat or crab gonad and digestive gland. Four experiments were made in which fresh foods were fed on one day a week to juvenile *P. serratus* otherwise receiving a compounded diet. The results, expressed as a percentage of the growth of prawns receiving the compounded diet only, are given in Table 11; they suggest that there is a growth-promoting factor in mussel mantle and show that the same or a similar factor may be present in crab gonad and digestive gland but not in shrimp tail meat. These experiments also showed that supplementation of Diet B with mussel mantle or crab gonad and digestive gland could improve its food value to the level of fresh mussel mantle itself. Growth on the supplemented diets, expressed as a percentage of the growth on fresh mussel mantle, was 94.8 per cent in experiment TR20 (see also Figure 2) and 114.2 and 115.0 per cent for the mussel- and crab-supplemented diets in experiment TR31. The possible nature of these growth-promoting constituents is discussed below.

In the light of the above results it is suggested that, while

TABLE 10 *Summary of experiments made to test the food value to juvenile* P. serratus *of mussel mantle which was processed in different ways but not rebound. The results are expressed as a percentage of the growth (mean percentage increase in live weight) on mussel mantle. See also Appendix table 4*

Experiment number and duration	Treatment of mussel mantle	Growth relative to growth on fresh mussel mantle (= 100) ± S.E.	
TR6, 4 weeks	Boiled, 100°C, 5 minutes	83.8	6.6
	Heated, 50°C, 5 minutes	84.8	7.2
TR16, 5 weeks	Boiled, 100°C, 5 minutes	50.0	7.2
	Heated, 50°C, 5 minutes	87.3	6.6
TR21, 4 weeks	Freeze-dried–rehydrated in sea water before feeding	77.9	6.3
TR26, 4 weeks	Deep-frozen–mantle removed from thawed mussels after at least 2 weeks frozen storage	58.7	6.8
TR30, 4 weeks	,,	30.9	6.4

TABLE 11 *Growth of juvenile* P. serratus *fed with compounded diets supplemented by fresh foods once per week. The results are expressed as a percentage of the growth (mean percentage increase in live weight) on the unsupplemented diet. See also Appendix table 5*

Experiment number and duration	Diet (fed 6 days per week) and binder	Fresh food supplement (1 day per week)	Growth relative to growth on unsupplemented diet (= 100) ± S.E.	
TR2, 3 weeks	Diet A—gelatin	Mussel mantle	131.0	10.8
TR3, 4 weeks	,,	,,	124.9	10.7
TR20*, 12 weeks	Diet B (27.2% protein)—agar	,,	156.3	10.3
TR31, 8 weeks	Diet B—agar	,,	138.3	8.4
	,,	Crab gonad and digestive gland	139.2	9.5
	,,	Shrimp tail meat	106.2	8.4

*This experiment is described more fully below (Diet 5) and shown in Figure 2.

the good food value of fresh mussel mantle or crab gonad and digestive gland reflects the presence of one or more labile growth-promoting substances, the good growth obtained on shrimp tail meat reflects the higher value of the proteins in this food to prawns. This is supported by the results of two further experiments. In the first, fresh and deep-frozen shrimp tail meat was fed to two groups of nine individually-held *P. serratus* juveniles. Growth (mean percentage increase in live weight) after 4 weeks was 237.0 and 259.0 per cent on the fresh and frozen food respectively and was not significantly different ($P > 0.1$). Deep-frozen and fresh shrimp were also found to be equally good foods for newly-metamorphosed juvenile *P. serratus* (Forster 1970). When mussels were similarly treated the food value of the mantle was substantially reduced (Table 10). In the second experiment two batches of nine individually-held prawns were fed either with Diet A or with the same diet in which the white fish meal component was replaced by freeze-dried mussel mantle. Both diets were bound with agar. Growth (mean percentage increase in live weight) after 4 weeks was 96.8 and 99.5 per cent for the freeze-dried mussel and white fish meal diets respectively and was not significantly different ($P > 0.1$). As a source of protein in this diet, therefore, freeze-dried mussel mantle was no better than white fish meal.

LONGER-TERM FEEDING EXPERIMENTS

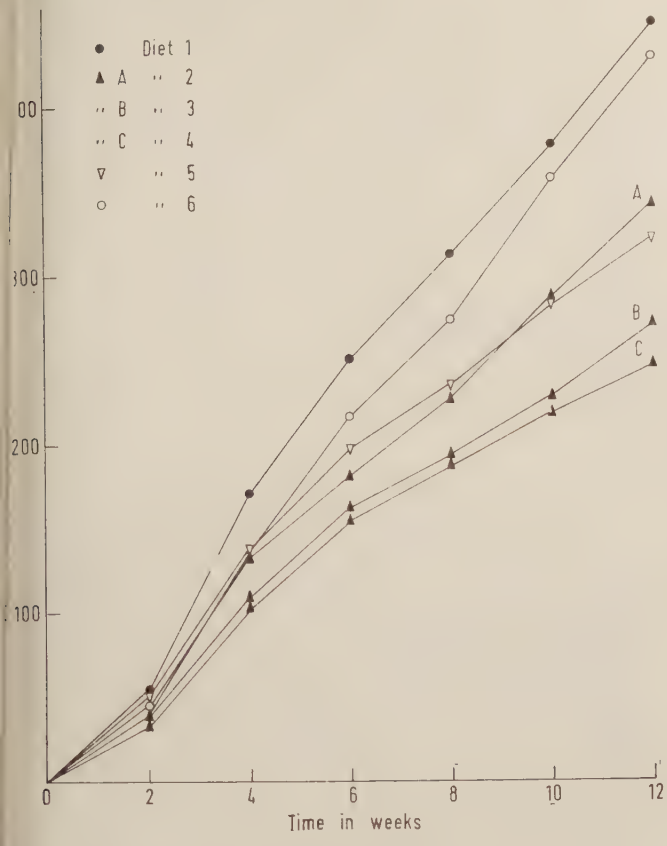
Conclusions drawn from the results of short-term feeding experiments are only of real value if it can be assumed that subsequent growth will follow the trends established durin the short term. It seems rather unlikely that a diet whic gives poor growth in a 4 week feeding experiment will, aft a longer period of time, start to induce substantially bett growth. Conversely, it is quite possible that diets inducin good short-term growth will subsequently be found lackin Therefore, although short-term experiments may be used t 'screen out' poor diets, conclusions about better diets coul be very misleading. Accordingly three longer-term exper ments were made and the results compared with thos obtained in 4 week feeding experiments.

Experiment with individuals

The following diets were fed to six groups of nin individually-held *P. serratus* juveniles for 12 weeks:

1 mussel mantle;
2 Diet B (38.9 per cent protein);
3 and 4 Diet B with the protein level reduced to 27.2 an 19.4 per cent respectively by dilution with a 95: w/w, wheat starch/corn oil mixture (see above)
5 as 3 + 1.5 per cent w/w vitamin supplemen (Table 4);
6 as 3 with mussel mantle fed once per week.

Diets 2–6 were bound with agar. The results are plotted in Figure 2. The growth observed on Diets 2, 3 and 4 support data presented in Figure 1, concerning the relationship between growth and different dietary protein levels. Growth on Diet 5 was slightly better than on Diet 3 but this difference was not significant at the 5 per cent level. However, there was



g. 2 Mean percentage live-weight increment of six groups of ie individually-held *P. serratus* juveniles fed with different ets (Diets 1-6, p. 8).

highly significant ($P < 0.001$) improvement in growth on iet 6 compared with Diet 3. This result has already been nsidered in connection with the presence of a growth ctor in mussel mantle.

Comparison of the growth after 4 and 12 weeks shows fferences in the growth on the compounded diets relative the growth on mussel mantle (= 100). On Diets 2, 3, 4 id 5 the growth relative to growth on mussel mantle tended decrease slightly (from 77.8 to 75.8 per cent, Diet 2; 64.2 60.7 per cent, Diet 3; 61.3 to 54.9 per cent, Diet 4; and 0.6 to 71.6 per cent, Diet 5), but on Diet 6 it increased (from 0.1 to 94.8 per cent). Apart from Diet 6 these differences re only small and inspection of Figure 2 shows that growth ends established in the first 4 weeks were approximately llowed during the rest of the experiment. If the experiment ad been finished after 4 weeks the results would have given reasonably good indication of the longer-term growth sponse to the different diets. A better estimate of longer-rm growth could have been made after 6 or 8 weeks, but ie advantage of this greater accuracy must be weighed gainst the extra time taken for its determination.

xperiments with populations

The feeding experiments which have been described so far ere all made with prawns kept individually so that the ossibility of cannibalism was completely avoided. However, study of the response of prawn populations to compounded iets is really more relevant if commercial prawn culture ystems are to be developed. This was undertaken in two xperiments using laboratory-reared juvenile *P. serratus* and *. platyceros* during the summer of 1970. In these experi-ients growth was estimated by live-weighing batches of rawns after first drying them on paper tissue (Forster 970), and is presented in the results as the increase in mean ve weight in each population.

Experiment with P. serratus

Six 1.2 × 1.2 × 0.3 m wooden tanks (Forster 1970) were each stocked at the beginning of June with 155 juvenile *P. serratus* (mean live weight 66.7 mg). The tanks were situated outdoors in direct sunlight but were covered with translucent sheets of PVC; these were painted green and reduced the light intensity at the water surface by 98.5 per cent. During June and the first three weeks in July sea water, recirculated from a 70 000 litre reservoir, flowed through each tank at a rate of one litre/minute; during the remainder of the experiment fresh sea water pumped from the Conway Estuary (Walne 1966) was circulated and run to waste. Recirculation at the beginning of the experiment was necessary to avoid using sea water contaminated with *Phaeocystis pouchetti* (Hariot) Lagerh., a colonial alga which blooms in the Conway Estuary in the early summer. During this bloom the sea water has a thick brown colour and has been found unsuitable for rearing oyster larvae (Walne 1970). Accordingly the reservoir tank was filled in early May, before the *Phaeocystis* bloom, and kept until the experiment started. The water temperature in the experimental tanks varied with the weather and also fluctuated diurnally. The maximum temperature recorded was 25.5°C and the minimum 10.2°C; the overall mean calculated from daily maximum and minimum temperatures was 18.1°C. Diurnal fluctuations ranged over as much as 9.6°C on hot sunny days but only over 1–3°C during cooler weather.

The following diets were tested, each being fed to duplicate prawn populations:

1 halves of mussel (on the shell);

2 Diet B + 1.5 per cent w/w vitamin supplement (Table 4) bound into a jelly with agar;

3 as 2, but bound into dry pellets with 2 per cent w/w polyvinyl alcohol (PVA)—see Forster (1972).

During the first 8 weeks of the experiment pellets 1.5 mm diameter and mean length 5 mm were used, but for the rest of the experiment the size was increased to 3 mm diameter × 7.5 mm mean length. The addition of extra vitamins had been found to confer only a very small advantage in experiments with individually-held prawns (Table 5) and they were included in the present diets only as a precautionary measure. Food was provided in excess every 24 hours. The ration was adjusted throughout the experiment according to the size of the prawns and the prevailing weather conditions. During colder weather food consumption was greatly reduced, but under normal conditions—water temperature 16–20°C—the compounded diet ration (dry weight) was approximately 7.5 per cent of the total live weight of the prawns. This was always sufficient for there to be some food remaining after 24 hours and this was removed by siphoning before more food was added. The mussel ration was increased through the experiment from four to eight halves per day.

The prawns were counted and weighed each month until the experiment was finished, after 95 days, on 3 September. The results are tabulated in Table 12. Expressed as a percentage of the mean increment on mussel, the growth of the two populations on the jellied food after 95 days was 78.1 and 81.6 per cent (mean 79.9 per cent). This agrees quite well with results of laboratory feeding experiments with individuals, in which values of 86.1 per cent (mean of nine separate 4 week experiments) and 75.8 per cent (in one 12 week experiment described above) were obtained. Growth on pellets, however, was rather better than had previously been obtained in short-term laboratory experiments with

TABLE 12 *Survival and growth of duplicate* P. serratus *populations held in outdoor tanks and fed with different diets*

Population	Number of prawns surviving on day				Mean live weight (mg) of prawns on day			
	0	36	67	95	0	36	67	95
	Diet of mussel							
1	155	144	135	121	66.7	420.1	811.1	1 147
2	155	146	129	115	66.7	441.8	895.3	1 298
	Diet B + 1.5 per cent vitamins, bound with agar (jelly)							
1	155	142	128	121	66.7	348.6	703.1	969.4
2	155	141	124	108	66.7	361.7	750.0	1 010
	Diet B + 1.5 per cent vitamins, bound with PVA (dry pellets)							
1	155	150	142	125	66.7	306.7	616.2	921.6
2	155	140	137	127	66.7	271.4	569.3	765.4

individuals (Forster 1972), in which mean growth on PVA-bound pellets, expressed as a percentage of the growth on an agar-bound diet, was 62.8 per cent. In the present experiment values of 92.6 and 75.5 per cent (mean 84.2 per cent) were obtained.

It is interesting to compare the growth curves for prawns in the outdoor experiment with similar curves for prawns in the 12 week laboratory experiment (Figures 2 and 3). The rate of growth in the outdoor populations was faster than that of individuals in the laboratory. This is in contrast to the results of Forster (1970), who reported that growth in laboratory populations was better than the growth of prawns held in outdoor tanks during the summer of 1967. It seems possible therefore that the confinement of individual prawns to relatively small containers may have a slight inhibitory effect on growth. Figure 3 also shows that growth trends in the outdoor populations on the different diets had been established after the first 36 days (first weighing). Short-term feeding experiments with populations might therefore be used for testing different diets, in the same way as experiments with individuals have been used in the studies described above.

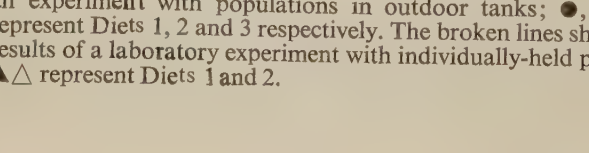


FIG. 3 Comparison of the growth of *P. serratus* juveniles in two types of feeding experiments. The full lines show the results of an experiment with populations in outdoor tanks; ●, △, ○ represent Diets 1, 2 and 3 respectively. The broken lines show the results of a laboratory experiment with individually-held prawns. ▲△ represent Diets 1 and 2.

One further observation is worth making. Measurem of individual total lengths (tip of rostrum-distral en telson) of the prawns from the six experimental populat were all very similarly distributed. Data for the structur each population are given in Table 13. These data show the observed differences in growth on the three diets re differences in the response of all the members of e population and are not simply due to the presence of a particularly large or small prawns in each group.

TABLE 13 *Data for the total length structure of duplicate populations of* P. serratus *after outdoor experiment in which three diets were tested*

Population	Number	Mean total length (mm)	Standard deviation	Coefficie of variat (%)
	Diet of mussel			
1	121	51.0	4.38	8.6
2	115	53.0	5.38	10.2
	Diet B + 1.5 per cent vitamins, bound with agar (jelly)			
1	121	48.5	4.61	9.5
2	108	49.3	4.98	10.1
	Diet B + 1.5 per cent vitamins, bound with PVA (dry pellets)			
1	125	47.8	4.66	9.7
2	127	44.7	4.75	10.6

Experiment with P. platyceros

Three fibreglass tanks, 91 × 76 × 46 cm (depth of wa 30 cm), were each stocked with 94 juvenile *P. platyceros*. T tanks were situated indoors and supplied with 2 litres p minute of sea water, recirculated from a 12 000 litre res voir. The temperature remained fairly constant, gradua dropping from 19 to 15°C during the experiment. Labo tory-reared prawns were used which were the survivo from an attempted experiment to keep *P. platyceros* in o door tanks similar to those used in the above experime with *P. serratus*. Early in this attempt heavy mortalities h occurred; these were attributed to excessively high wa temperatures—up to 25°C—which for this species is co siderably higher than normally encountered in the w (Butler 1969). The animals had therefore been subjected considerable stress early in their lives and their later grow

BLE 14 *Survival and growth of* Pandalus platyceros *populations held indoors and fed with different diets*

Population	Number of prawns surviving on day				Mean live weight (mg) of prawns on day			
	0	31	62	91	0	31	62	91
	Diet of mussel							
1	94	73	63	56	314	753	1 437	2 179
	Diet B + 1.5 per cent vitamins, bound with agar (jelly)							
1	94	57	42	37	330	623	1 012	1 257
	Diet B + 1.5 per cent vitamins, bound with PVA (dry pellets)							
1	94	67	58	47	314	597	836	1 021

d survival may not be typical. Nevertheless it was consi-ed worth while to compare their response to compounded d fresh foods in a feeding experiment.

The diets tested were the same as those in the experiments th *P. serratus* populations described above. The smaller llets (1.5 mm diameter) were fed during the first 4 weeks d for the remainder of the experiment larger pellets (3.0 n diameter) were provided. The ration of the com-unded diets (dry weight) provided daily was approxi-ately 10 per cent of the live weight of the prawns, although is was considerably in excess of their requirements. The ussel ration was increased through the experiment from ur to six halves of mussel, although this again represented nsiderable overfeeding. The prawns were counted and eighed each month for 3 months (91 days) and the results e tabulated in Table 14.

Survival was rather poor in this experiment but most of e mortalities occurred during the first month, when the awns may still have been weak following the adverse nditions in the outdoor tanks. For this reason observed fferences in survival between the different populations at e end of the experiment are not considered to be signi-ant. The differences in growth are very interesting, owever. After 31 days the mean increment on the com-ounded diets, expressed as a percentage of the growth on ussel, was 63.4 and 64.4 per cent for the jelly and pellets spectively, but after 91 days these values had dropped to 7.3 and 37.9 per cent. *P. serratus* fed with these diets aintained their growth relative to mussel over 95 days but e performance of *P. platyceros* slowly declined. The reason r this is not known, but the experiment shows clearly how e response to compounded diets may differ markedly etween different prawn species and reveals how con-lusions drawn from the results of short-term experiments ould be very misleading. Although the results of short- and nger-term experiments with *P. serratus* fed Diet B showed ood agreement, trials covering the whole period from venile to marketable-sized prawns or even through one or nore generations are necessary before a precise assessment f the dietary value can be made.

Discussion

The experiments described in this paper were conceived as part of a preliminary investigation into the problems of compounding practical rations for prawns. The experiments have all been of relatively short duration and thus require cautious interpretation. Also, they have been made with only two prawn species, so that general conclusions must be considered with this limitation in mind. Nevertheless, comparisons of growth in short-term experiments of juvenile prawns fed on fresh foods and diets formulated from standard animal feed ingredients have demonstrated some of the difficulties of compounding prawn diets and have indicated the following problems and areas which need further investigation.

1 Difficulties may arise from the need to bind prawn diets so that they are stable in water. Experiments in which mussel mantle was processed and rebound in different ways suggested that the presence of a binder may adversely affect the value of the food. This was also demonstrated in two experiments with prawn populations in which the food value of a jellied (agar-bound) diet was shown to be superior to a dry pelleted (PVA-bound) diet. Differences in the value of bound foods are also described by Forster (1972), where it is reported that an agar-bound jellied diet was superior to gum-bound diets (pastes) which in turn were better than dry pellets. The food texture, moisture content or the nature of the binding material itself may therefore be critical and further work is needed on these aspects.

2 Experiments with processed mussel mantle suggested that there may be a labile growth factor in this food which stimulates growth in *P. serratus* juveniles. One experiment also suggested that there may be a similar factor in crab gonad or digestive gland. If the presence of these factors can be confirmed in further experiments and their activity demonstrated with other prawn species, then their isolation and identification would be most important. At present the possible nature of such components is entirely a matter for speculation, but it may be significant that growth factors were demonstrated in two fresh foods which contained gonad material. Such tissues might be expected to contain hormones of the steroid group. Hormones of this kind such as androgens, estrogens and progestogens are now used extensively to stimulate growth and fattening of meat-producing animals, either by mixing them with the food or by subcutaneous implantation (Maynard and Loosli 1969). A study of their influence on prawn growth might therefore prove rewarding.

3 The source of the major protein components in prawn diets is most important, as was shown in experiments (Table 2) in which the value of a number of high protein food meals was tested. In these experiments no investigation was undertaken of the possible advantages of mixing or blending high protein meals of different origins. However, this is an important aspect, since it could lead to improve-

ments in the nutritional value of the diets or to substantial economies if quantities of less expensive high protein meals could be used. Further work is required therefore to test the value of different high protein meal mixtures.

4 Ultimately, if prawn diets are to be formulated with confidence from a wide variety of basic food ingredients, a detailed knowledge will be needed of the nutritional requirements of the species under cultivation. At present such information concerning decapod Crustacea is extremely limited. There are however some indications that the nutritional requirements of this group may be similar in certain respects to those of higher animals. Experiments with two species, *Astacus astacus* (Zandee 1966*a*) and *Palaemon serratus* (Cowey and Forster 1971), have been reported in which the biosynthesis of amino acids from ^{14}C-labelled precursors was studied. These studies have shown that the ability of these species to synthesize certain amino acids—which are thus considered non-essential in the diet—resembles that of other animal species for which amino acid requirements are known, e.g. *Drosophila melanogaster* (Sang and King 1961), rats and pigs (Maynard and Loosli 1969), Pacific salmon (Halver, DeLong and Mertz 1957) and plaice and sole (Cowey, Adron and Blair 1970). In certain other respects, however, the nutritional requirements of Decapoda may differ from those of higher animals. For example ^{14}C-labelled precursor experiments with *Astacus astacus* (Zandee 1966*b*) and the blue crab *Callinectes sapidus* Rathbun (Whitney 1970) have shown that these species are incapable of synthesizing cholesterol and that this, or other sterols, are therefore required in the diet. Further studies of this kind with prawns are needed and also experiments with purified diets, so that precise quantitative requirements of amino acids, vitamins and other essential nutrients may be defined. In the meantime diets must be formulated on an empirical basis, using ingredients of recognized nutritive value together with any supplements which experience shows enhance growth.

It is interesting to note in this context a report by Kanazawa *et al.* (1970) which describes preliminary experiments in the development of a chemically defined compounded diet for the prawn *Penaeus japonicus*. The diets contained purified soy-bean protein—supplemented with methionine and tryptophan—as the major nitrogen source, plus various other nutrients which have been successfully used in diets developed for silkworms, chinook salmon and brine shrimp (*Artemia salina*). Diets were bound either by heat coagulation of the soy-bean protein or by the addition of 4 per cent agar. In short-term feeding experiments growth of juvenile *P. japonicus* fed on these diets was compared with growth on a fresh diet of short-necked clam (*Tapes philippinarum*). The results show interesting similarities with some of the findings of the present study. Prawns fed with the compounded diets maintained a healthy condition but growth was not as good as on the fresh clam food. Diets giving the best growth were those which had a higher moisture content and which were bound with agar. Furthermore, subsequent testing of the best diet gave growth rates in the range 65–87 per cent of the growth achieved on the clam control diet.

5 It is important to consider the limitations on the costs of prawn diets which may be imposed by the nature and efficiency of a prawn culture system. The most important factor in this respect is the efficiency with which the food is converted by prawns into their own tissues. The development of specially formulated diets for the intensive culture of certain fish has enabled extremely efficient conversion rates to be achieved. For example, conversion rate 0.9–1.0:1 and 1.3–1.5:1 (dry weight of food: live weig fish) are considered normal for first- and second-year ca (Anon. 1970). For prawns it is considered that conve rates will be rather less efficient than for fish becaus losses incurred due to moulting, and values of 2–3:1 m be anticipated. This is supported by data of Forster (1 which showed that conversion by *P. serratus* juveniles w fed crushed whole shrimp became less efficient as increased in size from 36 to 444 mg live weight. It suggested that conversion efficiency by larger prawns c shrimp diet was unlikely to be better than 10:1 (wet we of food: live weight of prawn) or approximately 2.5:1 weight of food: live weight of prawn). In another experim Forster (unpublished data), found a conversion of 2.3 (dry weight of food: live weight of prawn) for *P. serr* juveniles (0.75–1 g live weight) fed with mussel mar During the present study no estimates of convers efficiencies were made, due mainly to the practical d culties of determining accurately the food consumption individual prawns fed compounded diets. It was conside that first priority should be given to obtaining good gro rates on compounded diets and, once achieved, this co be followed by studies on conversion efficiency.

The cost of animal feeds, in general, reflects their prot content and to this extent the cost of prawn diets v probably be similar to certain fish diets. Experime described above indicated that for *P. serratus* dietary prot levels of between 30 and 40 per cent may be satisfacto and levels of this order are characteristic of commercial c fish feeds. Therefore, if conversion rates in prawns are fou to be higher than in fish, then feeding costs will also higher. The final permissible cost will depend on the co version rates which can be achieved and on the efficien of the prawn culture technique, but before firm limits c be defined there is much more that needs to be kno concerning other aspects of prawn husbandry.

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ppendix

Text tables 2, 5, 9, 10 and 11 of this paper results of eral different feeding experiments have been summarized d comparisons of growth made by reference to growth on ontrol diet. In each case the growth on the control diet s been considered as 100 per cent, so that comparisons of tary value can be made easily by inspection. Presented in s form, however, the data do not include the actual values growth (mean percentage increments in live weight) ich were obtained in the different feeding experiments. ese data, together with the growth observed on the con- l diets, are given for each experiment in the following bles (Appendix tables 1–5). In Appendix tables 1, 2 and in addition to values for the growth on the control com- unded diets, values are given for the growth of a second ntrol group fed on mussel mantle. In the experiments mmarized by Text tables 9 and 10 and Appendix tables 3 d 4, mussel mantle itself was the primary control food. lso included in the Appendix tables are values for the itial mean live weight of the prawns in the different periments. These values represent the mean initial live eight of both the control and experimental groups taken gether. Since the prawns for these experiments were lected at random from populations with a narrow size stribution—normally within 50 mg—differences between e initial mean live weight of control and experimental oups in any one experiment were only small.

APPENDIX TABLE 1 *Growth (mean percentage live-weight increment) data recorded in a series of feeding experiments lasting 4 weeks to compare the growth of juvenile* P. serratus *fed with diets containing different high protein meals substituted for white fish meal in Diet A (Text tab 1). The results are summarized in Text table 2. Values in parentheses are the standard errors of the means*

Experiment number	Test high protein meal	Series (see Text table 2)	% growth observed on			Initial mean weight of pr (mg)
			experimental diet	control Diet A	fresh mussel mantle	
TR5	Norwegian herring meal	1	58.4 (7.2)	79.1 (7.2)	156.4 (7.2)	276.2
	Peruvian fish-meal	1	75.9 (7.2)			
	Meat meal	1	52.7 (7.2)			
	Whale meat meal	1	36.7 (7.6)			
TR7	Freeze-dried fish-meal	1	68.5 (5.9)	82.1 (5.9)	144.7 (5.9)	206.4
	B.P. protein concentrate	1	56.7 (5.9)			
	Soya bean meal (ex.)	1	41.9 (5.9)			
TR8	Norwegian herring meal	2	80.6 (9.8)	90.1 (9.3)	207.6 (9.3)	122.5
	Peruvian fish-meal	2	77.6 (9.3)			
	Meat meal	2	57.4 (9.3)			
	Whale meat meal	2	42.1 (9.8)			
TR10	Freeze-dried fish-meal	2	122.6 (12.9)	132.9 (12.9)	221.3 (12.9)	126.3
	B.P. protein concentrate	2	93.2 (12.9)			
TR12	Norwegian shrimp meal	1	196.2 (12.6)	168.3 (12.6)	242.6 (13.4)	155.3
TR13	*P. serratus* meal	1	186.8 (12.0)	158.9 (12.0)	225.8 (12.0)	156.9
TR14	Norwegian shrimp meal	2	51.9 (7.5)	48.3 (7.0)	69.3 (6.6)	695.9
	Accelerated freeze-dried egg	1	12.0 (7.5)			
TR17	Casein	1	64.9 (9.3)	98.2 (9.3)	173.3 (9.3)	187.1
	Egg albumin	1	60.6 (9.8)			
TR22	Accelerated freeze-dried egg	2	60.0 (7.6)	79.7 (7.6)	142.6 (7.6)	167.7

APPENDIX TABLE 2 *Growth (mean percentage live-weight increment) data recorded in four feeding experiments to determine the influence of supplemental vitamins in Diets A and B (Text table 1) on the growth of* P. serratus *juveniles. The results are summarized in Text table 5. Values in parentheses are the standard errors of the means*

Experiment number and duration	Compounded diet used	Vitamin supplement level (%)	% growth observed on			Initial mean l weight of pra (mg)
			supplemented diet	unsupplemented diet (control)	fresh mussel mantle	
TR14, 4 weeks	Diet A, gelatin-bound	2.5	39.8 (7.5)	48.3 (7.0)	69.3 (6.6)	695.9
TR29, 4 weeks	Diet A, agar-bound	1.5	109.9 (8.0)	109.3 (8.0)	185.7 (8.0)	166.9
		2.5	105.7 (8.0)			
TR20, 12 weeks	Diet B (27.2% protein), agar-bound	1.5	323.5 (28.2)	274.1 (29.9)	451.7 (28.2)	161.6
TR31, 8 weeks	Diet B, agar-bound	1.5	424.9 (39.9)	386.5 (36.9)	467.8 (32.6)	174.3

APPENDIX TABLE 3 *Growth (mean live-weight increment) data recorded in a series of feeding experiments to test the food value to juvenile* P. serratus *of mussel mantle which was processed and bound in different ways. The results are summarized in Text table 9. Values in parentheses are the standard errors of the means*

Experiment number and duration	Experimental diet components		% growth observed on		Initial mean si of prawns (mg
	Mussel mantle preparation	Binder and concentration used	experimental diet	fresh mussel mantle (control)	
B1*, 3 weeks	Homogenized	Gelatin 6% w/v	55.9 (3.6)	120.9 (3.6)	9.0 mm (tot
		Sodium alginate 6% w/v	30.6 (3.8)		lengt
B2*, 3 weeks	,,	Gelatin 6% w/v	59.9 (3.1)	113.4 (3.1)	8.9 mm (tot
	,,	,, 10% ,,	50.3 (3.2)		lengt
	,,	,, 20% ,,	46.0 (3.1)		
TR2, 4 weeks	Oven-dried 80°C, 24 hours, milled	,, 20% w/w	54.8 (6.3)	71.4 (4.7)	249.8
TR3, 4 weeks	,,	,, 20% w/w	86.2 (9.7)	168.0 (10.3)	126.3
TR6, 4 weeks	Homogenized	,, 7.6% w/v	87.7 (10.6)	147.1 (9.6)	226.4
	Oven-dried 80°C, 24 hours, milled	,, 20% w/w	85.5 (11.8)		
	Freeze-dried, milled	,, 20% ,,	73.6 (10.6)		
TR12, 4 weeks	,,	Guar gum 5% w/w	116.7 (15.5)	242.6 (13.4)	155.3
TR21, 4 weeks	,,	Agar 3% w/w	123.9 (12.4)	210.1 (12.4)	149.2

*These experiments were made using newly-metamorphosed juvenile *P. serratus* and the growth increments and mean initial size were estimat in terms of total length.

NDIX TABLE 4 *Growth (mean percentage live-weight increment) data recorded in a series of feeding experiments to test the food value to* P. serratus *juveniles of mussel mantle which was processed in different ways but not rebound. The results are summarized in Text table 10. Values in parentheses are the standard errors of the means*

iment er and ion	Treatment of mussel mantle (experimental diet)	% growth observed on		Initial mean live weight of prawns (mg)
		experimental diet	fresh mussel mantle (control)	
4 weeks	Boiled, 100°C, 5 minutes	123.3 (9.6)	147.1 (9.6)	226.4
	Heated, 50°C, 5 minutes	124.7 (10.6)		
, 5 weeks	Boiled, 100°C, 5 minutes	126.6 (18.2)	253.1 (16.6)	168.8
	Heated, 50°C, 5 minutes	221.0 (16.6)		
, 4 weeks	Freeze-dried–rehydrated in sea water before feeding	163.7 (13.2)	210.1 (12.4)	149.2
, 4 weeks	Deep-frozen–mantle removed from thawed mussels after at least 2 weeks frozen storage	115.6 (13.4)	197.0 (14.2)	180.4
, 4 weeks	,,	62.5 (13.0)	202.2 (13.0)	158.4

ENDIX TABLE 5 *Growth (mean percentage live-weight increment) data recorded in four feeding experiments to determine the food value to juvenile* P. serratus *of Diets A and B (Text table 1) supplemented by fresh foods once per week. The results are summarized in Text table 11. Values in parentheses are the standard errors of the means*

eriment ber and tion	Compounded diet used and fresh food supplement	% growth observed on			Initial mean live weight of prawns (mg)
		supplemented diet	unsupplemented diet (control)	fresh mussel mantle	
, 3 weeks	Diet A, gelatin-bound + mussel mantle	60.4 (5.0)	46.1 (4.7)	71.4 (4.7)	249.8
, 4 weeks	,,	113.2 (9.7)	90.6 (9.7)	168.0 (10.3)	126.3
0. 12 weeks	Diet B (27.2% protein), agar-bound + mussel mantle	428.4 (28.2)	274.1 (29.9)	451.7 (28.2)	161.6
1, 8 weeks	Diet B, agar-bound + mussel mantle	534.4 (32.6)			
	Diet B, agar-bound + crab gonad and digestive gland	538.0 (36.9)	386.5 (36.9)	467.8 (32.6)	174.3
	Diet B, agar-bound + shrimp tail meat	410.4 (32.6)			

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